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SEARING OF LIGHT-WEIGHT FABRICS BY RUNNING CORDAGE

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SEARING OF LIGHTWEIGHT FABRICS BY RUNNING CORDAGE

by

J. E. Swallow

SUMMARY

Analysis of variance was applied to the residual breaking strengths of lightweight fabrics seared in 612 combinations of treatment and external conditions. Velocities of the running cordage greater than 13.5m/s caused increasingly severe damage, particularly at higher contact times. Silicone treatments were helpful in reducing searing of nylon fabrics if applied in sufficient quantity. Aromatic polyamide fabric did not lose strength by searing in the conditions examined.

Departmental Reference: Mat 269

CONTENTS

1 INTRODUCTION

A main contractor, a sub-contractor, and various Departments of the Procurement Executive, Ministry of Defence, participated in an investigation of the searing of fabrics by running cordage, e.g. lines. In parachutes, searing, generally caused by abnormal deployment, can lead to undesirable repair costs and logistic problems, or, in extreme cases, a risk of canopy failure with possibly fatal consequences.

The results are available only in the contractor's reports[1-4]. It was therefore considered desirable to publish the RAE contribution and review the work done, with the minimum necessary background, within a single Report. The opportunity has been taken to metricate all the results.

2 DIVISION OF EFFORT

The organisations which participated in the experiments, and their contributions, were:

(a) Irvin Great Britain Ltd., Letchworth: main contractor; arrangements for supply of fabrics, treated fabrics, lines and treated lines; contractual reporting;

(b) Albury Laboratories Ltd, Albury: sub-contractor for experimental work on searing;

(c) ICI Ltd, Nobel Division: analysis of silicone content of treated fabrics and lines;

(d) AQD/QNM2, Harefield: determination of residual strengths of seared fabrics in experiments 1 and 3;

(e) DR Mat/Mat R8: finance and technical management;

(f) RAE (Materials and Mathematics Departments): determination of residual strengths of seared fabrics in experiment 2; analysis of results.

3 SUMMARY OF EXPERIMENTS

3.1 Experiment 1: Assessment of treatments

(a) Apparatus[1,2]

A strip of fabric 25cm long × 5cm wide was tensioned between grips fitted at the end of a metal cantilever. The plane of the fabric was parallel to a braided nylon cord, such that when the cantilever was deflected and then released the fabric made a single contact, evenly across its width, with the cord,

the cantilever being caught on the rebound. The severity of the contact, in terms of time and pressure, was controlled by adjustable masses on the cantilever. The cord was in the form of a 30m length joined at its ends to form a closed loop, one end of which was passed round a fixed pulley, and the other round a pulley which could be moved so as to alter the tension in the cord. This latter pulley was connected to an electric motor capable of driving the cord at speeds up to 40m/s.

(b) Materials[1,2]

The fabric used was to specification[5] BS F118 No.854; this had a specification maximum mass of 54g/m^2 and minimum average breaking strength of 80N/cm. The cord was to specification DTD 481E cord No.5.

Treatments were applied to the fabric which subsequently still passed the specification, as follows:

Treatment	Code letter	Details	% uptake by mass on fabric
Normal finish	M	Scoured and heat set	
Khaki-dyed	K	Fabric M dyed khaki	
Spinners' lubricant	S	Water emulsion of hydrocarbon and surfactant	
Oil lubricant	W	Dispersion of hydrocarbon wax	0.5*
Silicone	C	Cationic emulsion of dimethyl silicone	1.25**

Similar treatments were applied to the cords, though in the case of the silicone none was subsequently detectable.

(c) Experimental design

A factorial experiment was arranged with the following combinations:

Fabric tension N/cm width	Load on cantilever N	Cord tension (each standing part) N	Velocity of cord m/s	Treatment of fabric	Treatment of cord
4.5, 9	0.5, 1.1, 1.7 (contact times 0.083, 0.100, 0.182 second)	45, 90	13.5, 27, 40	M†, K, S, W, C, M†	Untreated treated as fabric

* Level aimed for.

** Determined by ICI.

† Instead of the theoretically desirable randomising of the order of the tests, fabric M was tested first of the series, and again last of the series.

A full factorial experiment with these combinations would require $2 \times 3 \times 2 \times 3 \times 6 \times 2 = 432$ tests, which would have been too costly and time-consuming a task. Hence, a four-factor half-fractionation was adopted consisting of the combinations given in Table 1, repeated for each treatment of fabric and cord (= 216 tests). The response to each test was taken as the residual breaking strength of the fabric.

3.2 Experiment 2: Effect of different silicone treatments and levels

(a) Apparatus

This was as in experiment 1.

(b) Materials

The fabric and cord were as in experiment 1.

Treatments were applied to the fabric, which subsequently still passed the specification, as follows:

Treatment	Code letter	Details
Normal finish	M	Scoured and heat-set
Khaki-dyed	K	Fabric M dyed khaki
Silicone	D	Non-ionic emulsion of low viscosity
Silicone	E	Non-ionic emulsion of high viscosity

No treatment was applied to the cords.

(c) Experimental design

A factorial experiment was arranged with the following combinations:

Fabric tension N/cm width	Load on cantilever N	Cord tension (each standing part) N	Velocity of cord m/s	Colour of fabric	Silicone treatment	Nominal level of treatment %
4.5, 9	0.5, 1.1, 1.7	45, 90	13.5, 27, 40	M, K	D, E	0*, 0.2, 0.8**, 1.6**, 0*

* Instead of the theoretically desirable randomising of the order of the tests, the fabrics (M and K) were both tested with nominal level of treatment 0 first of each series, and again last of the series; the results were taken as common to both silicone treatments.

** % mean determined uptakes were on the average about 30% too low for the middle level and 25% too high for the highest level.

The same four-factor half-fractionation was adopted as in experiment 1. Thus, 18 × 2 (2 × 3 + 1 × 2) = 288 searing tests were done. The response to each test was taken as the residual breaking strength.

3.3 Experiment 3: Effect of different fabrics

(a) Apparatus

This was as in experiment 1.

(b) Materials

The cord was as in experiment 1. The fabric of experiment 1 was again tested, together with the following[3], chosen to be similar to that fabric, and all were undyed:

Fabric	Code letter	Mass per unit area, g/m^2
Medium-tenacity nylon-66	M	44
Nylon-6	Y	46
High-tenacity nylon-66	H	34
Aromatic polyamide	A	72*
Polyester	P	54

(c) Experimental design

A factorial experiment was arranged, with the following combinations:

Fabric tension	Load on cantilever	Cord tension (each standing part)	Velocity of cord	Fabrics
N/cm width	N	N	m/s	
4.5, 9	0.5, 1.1, 1.7	45, 90	13.5, 27, 40	M**, Y, H, A, P, M**

The same four-factor half-fractionation was adopted as in experiment 1; thus, 18 × 6 = 108 searing tests were done. The response to each test was taken as the residual breaking strength, expressed as a percentage of the original breaking strengths, which differed for the different fabrics.

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* This was the lightest available, and was constructed from 11 tex yarns.

** Instead of the theoretically desirable randomising of the order of the tests, fabric M was tested first of the series, and again last of the series.

4 RESULTS

4.1 Experiment 1

Although this was a six-factor experiment, a computer program for analysis of variance was available only up to five factors. The program was therefore applied to the data[1] twice, first by treating all the results at the two cord tensions as though they had been obtained from one cord tension, and then repeating by treating all those at the two fabric tensions as though they had resulted from one fabric tension. The two analyses were combined to give Table 2 and the two estimates of error obtained from the four- and five-factor interactions (which were assumed to be negligible), were pooled to give an averaged estimate of error. Fortunately, neither cord tension nor fabric tension was significant at the 99.9% level of probability. Table 2 gives results up to two-factor interactions, no higher-order interactions being important. Factors which were significant at the 99.9% level are indicated.

It is clear that the most important factors were the velocity of the cord and the load on the cantilever, and the effect of load was different according to velocity. Although the overall dependence of residual strength on velocity or load appeared to be linear (Table 3), the significance of the non-linear interactions showed that the dependence on velocity at a given load was not linear. The effect of treatment was dependent on both the velocity and the load. The effects of fabric tension, cord tension, and cord treatment on residual strength were negligible.

The tables of mean responses which achieved significance at the 99.9% level of probability are given in Appendix A. Examination of Appendix A in conjunction with the final column of Table 2, which gives the difference between the mean responses required to establish a difference with a 99.9% probability of being correct, allows the following conclusions to be drawn:

(i) At the lowest cantilever load, residual strength was scarcely affected by the velocity.

(ii) At the lowest velocity, residual strength was unaffected by the load.

(iii) The spinners' lubricant and silicone treatments significantly improved resistance to searing at medium and high velocity; at medium velocity or at medium load these treatments resulted in scarcely any loss in strength.

4.2 Experiment 2

Before breaking each specimen, the damage caused by searing was examined by microscope. It was found that the strength could be forecast quite accurately by observing the proportion of filaments or yarns which had been broken. It was also noted that distortion of the weave (i.e. widening of yarn spacing by the searing cord, with adjacent tightening up) did not cause a noticeable loss in strength.

Experiment 2 was a seven-factor experiment, which had to be analysed using the five-factor programs available. Two at a time of the variables had to be considered constant. Since experiment 1 showed that variations in cord tension and fabric tension had negligible effects, these were used to obtain the effects of type of silicone and level of silicone. Then, because type of silicone was found to be unimportant, the effects of cord tension and fabric tension were separately checked by considering fabric tension and type of silicone, and cord tension and type of silicone, respectively, as constant. These gave different estimates of error (taken as the high-order interactions), though fortunately the differences were not large and a mean error variance was used.

Table 4 gives a pooled analysis of the results, for conciseness, though it is not strictly accurate, and difficulties arose in ascribing degrees of freedom to the type of silicone and to the error. It may be remarked that some adjustment of the values quoted in Ref.4 has been made and a higher level of probability (99.9%) used, for consistency with experiments 1 and 3. Factors significant at the 99.9% level of probability are indicated.

The velocity of the cord, the load on the cantilever, the level of silicone and the interactive effect of load and velocity were the most important factors. The overall effect of type of silicone was negligible.

The tables of mean responses which achieved significance at the 99.9% level of probability are given in Appendix B. Examination of Appendix B in conjunction with the final column of Table 4 allows the following conclusions to be drawn:

(i) Residual strength was not affected by searing at the lowest velocity for any load on the cantilever.

(ii) Small amounts of silicone on the fabric did not improve performance significantly, but large amounts did.

4.3 Experiment 3

This was a five-factor experiment which was analysed, by analogy with the preceding experiments, as two four-factor experiments, treating cord tension and fabric tension as before. The error variance obtained from each analysis was taken as the mean of the variances of the four-factor interactions, which were negligibly different. Table 5 gives results up to two-factor interactions, no higher-order interactions being important. Factors significant at the 99.9% level of probability are indicated.

The most important factors were again the velocity of the cord and the load on the cantilever; the effect of load was also different according to the velocity. The material effect was also important, and, as noted below, the material effect depended on velocity for one of the fabrics.

The tables of mean responses which achieved significance at the 99.9% level of probability are given in Appendix C. The interactions between material and velocity and between the material and load on cantilever have been included because the differences required for significance at the 99.9% level were exceeded in an important manner by one of the fabrics, though these interactions were significant overall at less than the 99.9% level because of the preponderant effect of the other fabrics, which did not differ in respect of this interaction. The mean original breaking strengths for the fabrics are also given. Examination of Appendix C in conjunction with the final column of Table 5 allows the following conclusions to be drawn:

(i) For any of the fabrics or for any load on the cantilever residual strength was not affected by searing at the lowest velocity.

(ii) Higher velocity and any loads on the cantilever (except at the lowest velocity) caused appreciable losses in strength for all the fabrics, except for the aromatic polyamide which was not affected by any of the combinations tested.

5 CONCLUSIONS

(1) The effects of 612 combinations of treatments and external conditions on the resistance to searing of lightweight fabrics by running cordage assessed by residual breaking strength, were determined using analysis of variance.

(2) When the cord ran across the fabric at 13.5m/s, damage was negligible in all the circumstances examined; however, higher velocities had an increasingly severe effect on nylon and polyester fabrics, particularly if the contact times and pressures were increased.

(3) Silicone treatments were helpful in reducing searing of nylon if applied to give not less than about 1% uptake on the mass of the fabric.

(4) Fabric made from aromatic polyamide fibre did not lose strength by searing in any of the conditions examined.

(5) The breaking strength of seared fabrics could be forecast by observing broken filaments and yarns; weave distortion did not cause loss of strength.

Acknowledgment

The author thanks Mr. J.H. Cadwell, Mathematics Department, RAE, for arranging the computer programs.

Appendix A

TABLES OF SIGNIFICANT MEAN RESPONSES IN EXPERIMENT 1

Velocity effect:

13.5	27	40 m/s
93	71	42 N/cm

Load on cantilever effect:

0.5	1.1	1.7	N
89	67	50	N/cm

Velocity × load on cantilever interaction:

Load on cantilever N	Velocity m/s		
	13.5	27	40
0.5	93	90	84 N/cm
1.1	93	78	30 N/cm
1.7	93	45	11 N/cm

Treatment-of-fabric effect:

Fabric					
M	K	S	W	C	M
58	66	84	60	81	61 N/cm

Velocity × treatment-of-fabric interaction:

Velocity m/s	Fabric					
	M	K	S	W	C	M
13.5	90	97	93	93	91	92 N/cm
27	58	68	92	62	86	60 N/cm
40	26	34	67	26	67	31 N/cm

<u>Load on cantilever × treatment-of-fabric interaction:</u>

Load on cantilever N	Fabric						
	M	K	S	W	C	M	
0.5	82	92	93	85	91	91	N/cm
1.1	52	68	88	53	85	55	N/cm
1.7	41	39	72	43	69	37	N/cm

Appendix B

TABLES OF SIGNIFICANT MEAN RESPONSES IN EXPERIMENT 2

Velocity effect:

13.5	27	40 m/s
93	60	14 N/cm

Load on cantilever effect:

0.5	1.1	1.7 N
69	54	43 N/cm

Silicone level effect:

0	0.2	0.8	1.6	0 %
44	50	60	68	52 N/cm

Velocity × load on cantilever interaction:

Velocity m/s	Load on cantilever N		
	0.5	1.1	1.7 N
13.5	94	93	93 N/cm
27	84	60	35 N/cm
40	29	10	2 N/cm

Appendix C

TABLES OF SIGNIFICANT MEAN PERCENTAGE RESPONSES IN EXPERIMENT 3

(a) Mean fabric strength (original)

Fabric	M	Y	H	A	P
Breaking strength (mean of 5), N/cm	87	85	94	125	102

(b) Effects, expressed as percentages of mean strengths

Velocity effect:

13.5	27	40	m/s
100	62	38	%

Load on cantilever effect:

0.5	1.1	1.7	N
85	64	50	%

Material effect:

M	Y	H	A	P	M	
65	56	56	100	50	72	%

Velocity × load on cantilever interaction:

Velocity m/s	Load on cantilever N			
	0.5	1.1	1.7	
13.5	99	100	100	%
27	86	67	33	%
40	71	27	17	%

Velocity × material interaction:

Velocity m/s	Material					
	M	Y	H	A	P	M
13.5	100	99	99	100	99	102 %
27	55	54	42	100	38	81 %
40	39	16	28	100	13	34 %

Load on cantilever × material interaction:

Load on cantilever N	Material					
	M	Y	H	A	P	M
0.5	90	66	92	101	63	99 %
1.1	67	57	43	100	50	70 %
1.7	37	47	35	100	36	48 %

Table 1

EXPERIMENTAL DESIGN

Test No.	Fabric tension N/cm	Load on cantilever N	Cord tension N	Velocity of cord m/s
1	9	0.5	45	13.5
2	9	1.1	45	40
3	9	1.7	45	27
4	4.5	0.5	90	13.5
5	4.5	1.1	90	40
6	4.5	1.7	90	27
7	9	1.1	90	13.5
8	9	0.5	90	27
9	9	1.7	90	40
10	4.5	1.1	45	13.5
11	4.5	0.5	45	27
12	4.5	1.7	45	40
13	9	1.7	90	13.5
14	9	0.5	90	40
15	9	1.1	90	27
16	4.5	1.7	45	13.5
17	4.5	0.5	45	40
18	4.5	1.1	45	27

Table 2

ANALYSIS OF VARIANCE OF EXPERIMENT 1

Effect	No. of levels	No. of degrees of freedom	Variance ratio	Difference between mean responses required for 99.9% probability* N/cm
Fabric tension, F	2	1	1.1	6
Load on cantilever, L (total)	3	2	156 G	7
Cord tension, J	2	1	4.7	6
Velocity of cord, V (total)	3	2	265 G	7
Treatment of fabric, T	6	5	27 G	10
Treatment of cord, B	2	1	1.4	6
FL	6	2	2.2	10
FJ	4		Not obtained	
FV	6	2	0.1	10
FT	12	5	1.6	15
FB	4	1	0.3	8
LJ	6	2	1.0	10
LV (total)	9	4	54 G	13
LT (total)	18	10	5.0G	19
LB	6	2	0.9	10
JV	6	2	1.6	10
JT	12	5	1.4	15
JB	4	1	0.1	8
VT (total)	18	10	7.5G	19
VB	6	2	0.0	10
TB	12	5	4.6	15
Error + 4- and 5-factor interactions		84	Variance 155	
TOTAL	216			

* Calculated from: difference between mean responses = Student's t (2 × residual variance × No. of levels / total No. of levels)$^{\frac{1}{2}}$
with
2(total No. of levels/No. of levels - 1) degrees of freedom.

G Significant at 99.9% level of probability.

Table 3

LINEARITY OF RESPONSES FROM EXPERIMENT 1

Effect	No. of degrees of freedom	Variance ratio
LV (linear)	1	177 G
L^2V	1	14.6G
LV^2	1	2.6
L^2V^2	1	22.7G
LT (linear)	5	7.0G
L^2T	5	3.0
VT (linear)	5	13.9G
V^2T	5	1.1
L (linear)	1	310 G
L^2	1	1.7
V (linear)	1	526 G
V^2	1	3.6

G Significant at 99.9% level of probability.

Table 4

ANALYSIS OF VARIANCE OF EXPERIMENT 2

Effect	No. of levels	No. of degrees of freedom	Variance ratio	Difference between mean responses required for 99.9% probability* N/cm
Fabric tension, F	2	1	2.2	10
Load on cantilever, L	3	2	38.7G	12
Cord tension, J	2	1	4.0	10
Velocity of cord, V	3	2	361 G	12
Type of silicone, Z	2	1	0.1	10
Level of silicone, R	5	4	13.7G	17
Colour of fabric, Q	2	1	1.9	10
FL	6	2	1.0	19
FJ	4		Not obtained	
FV	6	2	0.7	19
FZ	4		Not obtained	
FR	10	4	1.2	25
FQ	4	1	1.9	15
LJ	6	2	0.7	19
LV	9	4	11.8G	23
LZ	6	2	1.4	19
LR	15	8	1.0	32
LQ	6	2	2.2	19
JV	6	2	1.0	19
JZ	4		Not obtained	
JR	10	4	0.4	25
JQ	4	1	2.7	15
VZ	6	2	0.8	19
VR	15	8	4.9	32
VQ	6	2	1.0	19
ZR	10	4	4.0	25
ZQ	4	1	0.1	15
RQ	10	4	1.4	25
Error + higher order interactions		16	Mean variance 416	
TOTAL	288			

* Calculated from: difference between mean responses = Student's t (2 × residual variance × No. of levels/total No. of levels)$^{\frac{1}{2}}$
with
2(total No. of levels/No. of levels − 1) degrees of freedom.

G Significant at 99.9% level of probability.

Table 5

ANALYSIS OF VARIANCE OF EXPERIMENT 3

Effect	No. of levels	No. of degrees of freedom	Variance ratio	Difference between mean responses required for 99.9% probability* N/cm
Fabric tension, F	2	1	5.7	9
Load on cantilever, L	3	2	26.7G	12
Cord tension, J	2	1	1.0	9
Velocity of cord, V	3	2	83.6G	12
Material, U	6	5	14.2G	17
FL	6	2	0.8	17
FJ	4		Not obtained	
FV	6	2	1.1	17
FU	12	5	2.0	27
LJ	6	2	0.8	17
LV	9	4	8.7G	22
LU	18	10	2.2	38
JV	6	2	0.4	17
JU	12	5	0.4	27
VU	18	10	4.4	38
Error + 4-factor interaction		20	Variance 415	
TOTAL	108			

* Calculated from: difference between mean responses = Student's t (2 × residual variance × No. of levels/total No. of levels)$^{\frac{1}{2}}$
with
2(total No. of levels/No. of levels − 1) degrees of freedom.

G Significant at 99.9% level of probability.

SYMBOLS

Symbol	Definition	Experiment
A	fabric from aromatic polyamide fibre	3
B	treatment of cord (either none, or as T)	1
C	silicone treatment (cationic emulsion of dimethyl silicone)	1
D	silicone treatment (non-ionic low-viscosity emulsion)	2
E	silicone treatment (non-ionic high-viscosity emulsion)	2
F	fabric tension, N/cm width	1,2,3
G	significant at 99.9% level of probability	1,2,3
H	fabric from high-tenacity nylon-66 fibre	3
J	cord tension, N	1,2,3
K	khaki-dyed fabric M	1,2
L	load on cantilever, N	1,2,3
M	fabric from normal finish (scoured and heat set) medium-tenacity nylon-66 fibre	1,2
N	Newtons (tension and strength)	1,2,3
P	fabric from polyester fibre	2
Q	colour of fabric (K or M)	2
R	level of silicone, %	2
S	Spinner's lubricant	1
T	treatment of fabric	1
U	material of fabric	3
V	velocity of cord, m/s	1
W	oil lubricant	1
Y	fabric from nylon-6 fibre	3
Z	type of silicone (D or E)	2

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17. Abstract

Analysis of variance was applied to the residual breaking strengths of lightweight fabrics seared in 612 combinations of treatment and external conditions. Velocities of the running cordage greater than 13.5m/s caused increasingly severe damage, particularly at higher contact times. Silicone treatments were helpful in reducing searing of nylon fabrics if applied in sufficient quantity. Aromatic polyamide fabric did not lose strength by searing in the conditions examined.

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